# The Revised Space Environment Models in CRÈME-MC, a replacement for CREME96

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The CREME96 model has been available on the WWW for more than 10 years now. While principally for the estimation of radiation effects on spacecraft electronics, it contains space radiation environment models that have been used for instrument design calculations, estimation of instrumental background, estimation of radiation hazards and may other purposes. Because of the evolution of electronic part design we have found it necessary to revise CREME96, creating CRÈME-MC. As part of this revision, we are revising and extending the environmental models in CREME96. This talk will describe the revised radiation environment models that are being made available in CRÈME-MC.

# The Revised Space Environment Models in CREME-MC
## A replacement for CREME96

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# Background

- **The CREME96 model is being revised because**
  - It is not capable of estimating radiation effects in the latest generation of electronic components
- **As part of this revision the environmental models are being revised and extended.**
  - The Galactic Cosmic Ray Model has been replaced with the latest Nymmik model (*now in beta testing*)
  - A model has been added to describe the lunar neutron albedo environment (*now in beta testing*)
  - The geomagnetic cutoff model will be revised
  - AP-9/AE-9 will used for trapped radiation
  - A Probabilistic model for solar energetic particles will be added

# Objective

- Develop a tool to provide a description of a reference space radiation environment that:
  - Will not be exceeded at a user-specified confidence level
  - Will provide reference environments for:
    - Peak flux
    - Event-integrated fluence
    - Mission-integrated fluence
  - The reference environments consists of:
  - Elemental energy spectra
  - For protons, helium and heavier ions

# Geomagnetic Cutoff

- **The geomagnetic cutoff model will be replaced by the 2006 Shea and Smart model**
- **This new model is based tracing cosmic ray trajectories through:**
  - The Tsyganenko magnetospheric field model
  - International Geomagnetic Reference Field.
- **The geomagnetic cutoff rigidity interpolation tool (Smart et al., 2006) will be added.**
  - Gives cutoffs for any orbit

# Trapped Radiation Model

- **We plan to replace AP8/AE8 in CREME96 with AP9/AE9**
  - Currently under development by a team lead by Greg Ginet of MIT Lincoln Laboratory
- **AP9/AE9 will provide a definitive model of the trapped energetic particle environment**
  - Probability of occurrence (percentile levels) for flux and fluence averaged over different exposure periods
  - Broad energy ranges from keV plasma to GeV protons
  - Complete spatial coverage with sufficient resolution
  - Indications of uncertainty
- **AP9/AE9 is currently in beta testing**

# Solar Energetic Particle Model

- **To provide models of the solar energetic particle (SEP) radiation environment in space that can:**

  - serve as reference environments for reliable spacecraft design

  - Provide risk assessments mission planning

  and

  - Provide accurate estimates for instrument design

# Grand Plan for the SEP Model

- Step 1: Develop a data base of SPE measurements that:
  - Follows consistent selection rules
  - Consists of statistically independent episodes of solar activity
- Step 2: Fit the elemental spectra for each episode with spectral forms such as the Ellison-Ramaty Model
  - This makes it possible to determine the flux (or fluence) above a common set of energy thresholds.

# Grand Plan- Continued

- Step 3: Construct Cumulative flux (or fluence) distributions for a standard set of energy thresholds
  - fit these with Xapsos' truncated exponential distribution to obtain initial distributions for each energy
- Step 4: Determine the frequency of SPE episodes during solar active periods and use this frequency to:
  - Define a Poisson (or Burrell) distribution for each element
- Step 5: Convolve the initial distributions with the Poisson distributions to obtain extreme value distributions for each element at each energy

# Grand Plan - Continued

- Step 6: Construct reference energy spectra for each element
  - This requires user input on:
    - Mission start date and duration
    - Choice of peak flux, event-integrated fluence or mission-integrated fluence reference spectra
    - Choice of Confidence level
- Step 7: Fit the reference spectra with the best-fit spectral form so that the final result is an energy spectrum for each element.

# Other Considerations

- In defining the initial distributions, we must also take into account the uncertainty in the parameters of the initial distributions determined by the fits to the cumulative flux (or fluence) distributions.
  - Xapsos has suggested a bootstrap procedure for this
- We must consider the uncertainty in the episode frequency in defining the Poisson distributions for each element and use the Burrell distribution if needed.
- Finally, we must investigate the solar cycle dependence.

# So, where are we?

- We have a partial collections of proton-episode integrated spectra and proton peak spectra
  - We are working on testing the consistency of the selection criteria for these spectra.
    - We are using NOAA's criteria to select events and their starting and ending dates
  - We have developed software to integrate the event proton fluences between these dates from the GOES missions.
- We have reviewed the literature on the reliability of SPE measurements in space
- We have tested eight functions for fitting spectra and determined the three that are most likely to fit any SPE event spectrum.
- We have make a simple test fitting of a complete set the peak proton fluxes above 10 MeV

# NOAA Selection Criterion

- SWO defines the start of a proton event to be the first of 3 consecutive data points with fluxes greater than or equal to 10 pfu. The end of an event is the last time the flux was greater than or equal to 10 pfu.

- 1 pfu = 1 proton/$cm^2$.sec.ster

# Examples of > 10 MeV Proton Flux Plots
## (dark green curves)
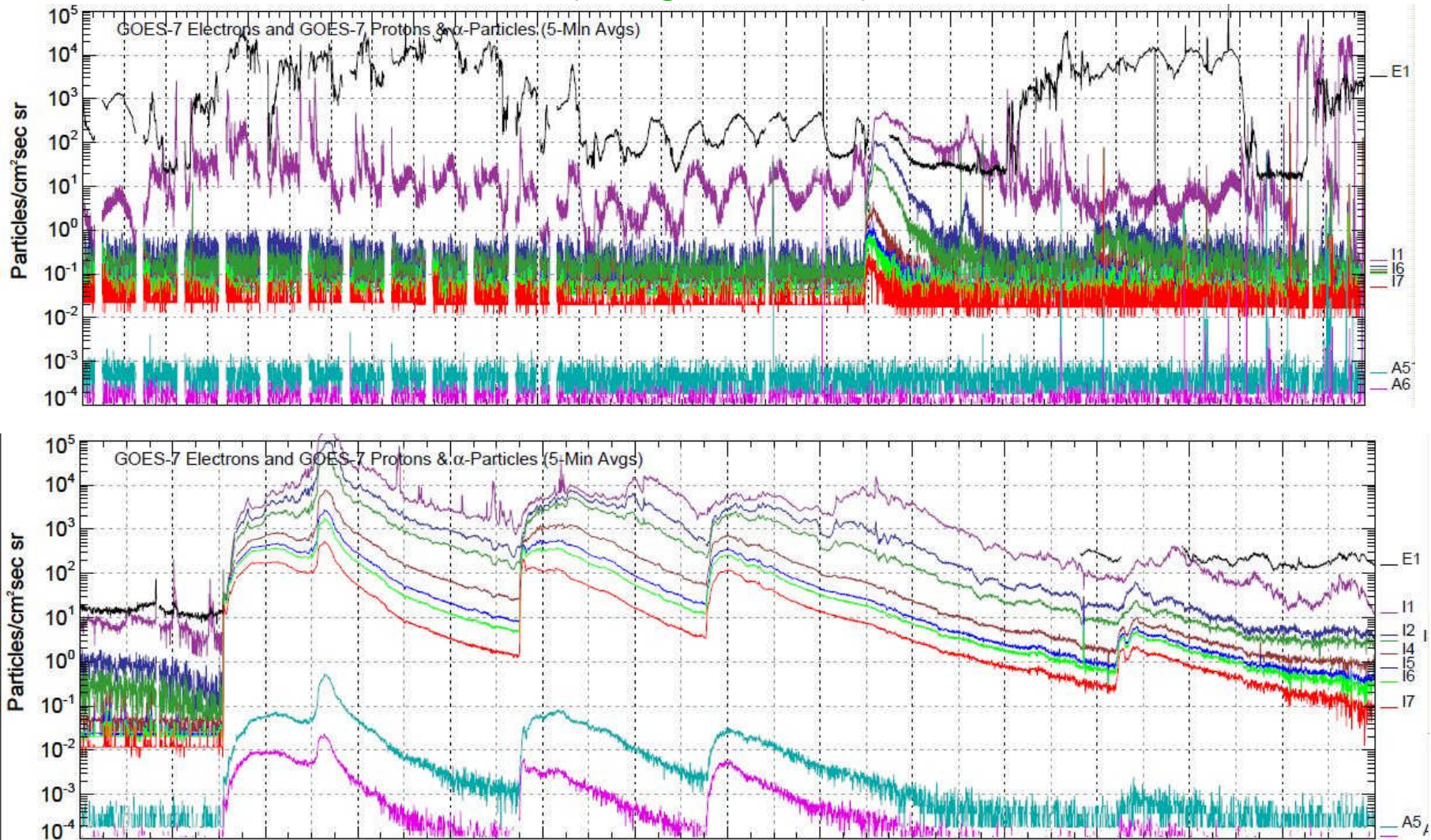
# Initial Distribution for Proton Peak Flux > 10 MeV for May 1967 to Dec 2006
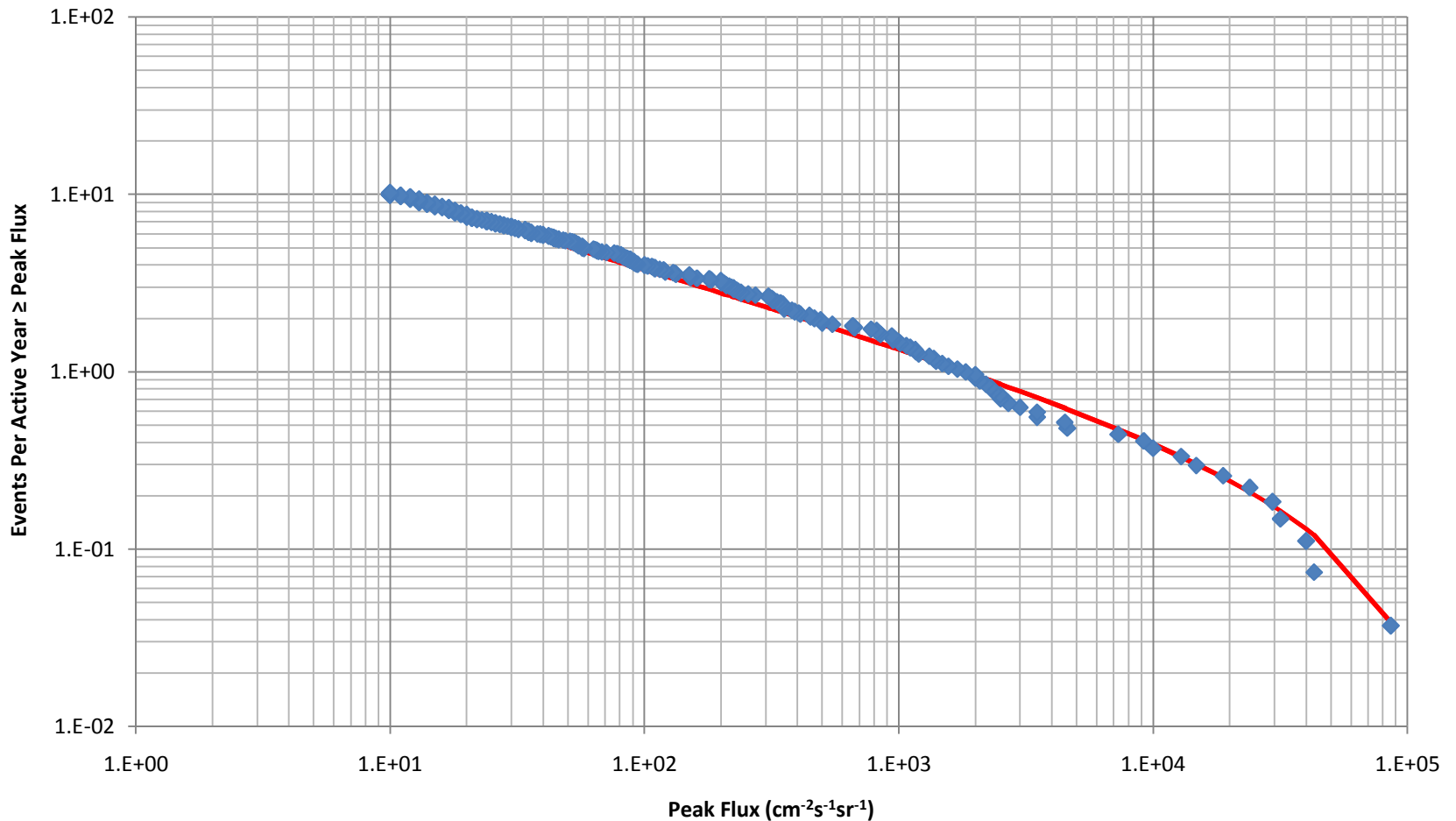
# Initial Distribution

- The initial Distribution is:

$$N(\phi) = N_{tot}(\phi^{-b} - \phi_{max}^{-b})/(\phi_{min}^{-b} - \phi_{max}^{-b})$$

- Where

  - $\phi_{min}$ = 10
  - $N_{tot}$ = 10
  - $b$ = 0.41 and
  - $\phi_{max}$ = 1.3X10$^5$

# Current Databases

- Peak Proton Flux
  - E > 10 MeV
  - 6/1967 through 12/2006
- Event-integrated Proton Fluences
  - 6/1966 through 10/1995
  - Energy Binning Ranges from:
    - 10 to 150 MeV in 17 energy bins to
    - 1 to 300 MeV in 23 energy bins
- Daily-integrated Proton fluences
  - 11/1973 through 10/2001
  - 1.01 to 398 MeV in 29 energy bins

# Data Reliability

This is a rather sad story
- The best that can be done is to find instruments that agree on the flux consistently within a factor of two
- Even then it is, in some cases, necessary to choose a trusted instrument and renormalize instruments in overlapping time periods to this one.
- Currently, for protons, we are stuck with some GOES instruments that are not the best.
  - There is also ERNIE on SOHO, but it saturates in large events.
- For helium and heavy ions we have ACE and it is reasonably consistent with the CRN instrument on IMP-8 that is a trusted reference.

# Summary

- **CREME96 is currently available at https://creme-mc.isde.vanderbilt.edu/**
  - Note that the NRL site is closing
- **The revised model, CRÈME-MC will be released in 2011.**
- **The environmental models described here will become available in CRÈME-MC as they are released**